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Safe and effective nuclear power plant life cycle management towards decommissioning

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FOREWORD

A reliable and adequate supply of energy, in the form of electricity, is indispensable for economic development. Thus providing electricity safely and reliably is an essential political, economic and social requirement. The safe operation of a nuclear power plant is generally acknowledged as contributing to society's success and promoting economic performance within those Member States that have a nuclear electricity generation capacity.

A nuclear power plant must be managed in a safe and efficient manner throughout all the life cycle stages from design through decommissioning, with the overall aim of delivering socio-economic success for the nuclear power plant owner and Member State.

The consequences of management decisions about nuclear power plants can have profound economic impacts for the nuclear power plant owner, and possibly for the national economy. In addition, the consequence of a major failure or accident can have catastrophic national socio-economic effects that may be felt internationally.

Most nuclear power plants have an operating life of up to and in some cases beyond 40 years and conducting its business under the watchful eye of national and international representatives of governments, pressure groups, and the news media.

Given the very long term nature of a nuclear power plant and its associated site, it becomes essential to adopt a similarly long term approach to the consequences of decision making and strategic direction from early in the life of the nuclear power plant. Many management decisions will have significant implications when their outcomes can affect the nuclear power plant for many decades and some consequences will only be apparent in similar time scales.

The safe and effective management of a nuclear power plant therefore requires dramatically different perspectives in time from the majority of other industries. The impact of some decisions extends beyond the normal strategic perspective of both owners and governments.

Additionally there is an acknowledged expectation that all waste, by products and structures associated with the nuclear power plant will be actively managed at all times, and that when no longer generating power, the site will be removed from regulatory control to a greater or lesser extent.

As a consequence strategic decisions should be considered and taken carefully as it is feasible that decisions taken today may:

- Have an impact which will only be felt decades later
- Prejudice later options and possibly lead to financial penalties being incurred
- Need to be extensively reviewed by independent authorities a long time after the decision was made.

For these reasons, decision making for a nuclear power plant must:

- Be based on objective data
- Take account of stakeholder interests
- Balance risks and opportunities
- Include an assessment of the longer term impact

– Be adequately recorded to communicate the rationale to future management teams so that they understand the context of, and reasons for previous decisions.

It is with the intention of promoting and communicating this long-term perspective or the need for effective life cycle management among senior managers and policy or strategy makers, that this publication has been prepared.

This publication provides an indication of the topics and issues associated with management decision making through the nuclear power plant life cycle, which have the potential to impact effective decommissioning.

This guidance provides a signpost on the topics and issues which are important in this strategic decision making and provides a collection of objective information for those strategists that will identify options and information pertinent to the final business decisions.

The safety conscious management culture, which has proven successful in today's nuclear business, has taken time to develop. Many utilities have difficulty sustaining this culture during the transitions that are intrinsic to the changes that occur during the phases of a nuclear power plant life cycle. Properly managed, however, plant life management can enhance nuclear safety, plant reliability and cost competitiveness, from the design stage to decommissioning.

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1. INTRODUCTION

1.1. Background

Given the very long-term nature of a nuclear power plant and its associated site, it is essential to adopt a similarly long-term approach to the consequences of decision making and strategic direction from an early stage in the life of the nuclear power plant. Some management decisions will have significant implications and consequences that could affect the nuclear power plant for many decades.

There is a large amount of published guidance on life cycle management for nuclear power plants, from the IAEA and other internationally recognized bodies. The topics that affect life cycle management have not been directly addressed in one publication, as the topics have emerged as nuclear power plants have moved through the life cycle stages, and the owners and utilities have addressed the topics when the need arose. This approach may not have brought the greatest economic benefits to the organizations, and realization has grown that there are benefits in managing some aspects of nuclear power plant design and operation in order to make the decommissioning process more effective.

In managing the life cycle stages of a nuclear power plant, many decisions have to be taken which can influence safe operation, but which must also balance long term stewardship of the organizations assets. Managing nuclear liabilities and assets requires profound understanding of the stages which make up the total life cycle of the nuclear power plant, the mission of the owners, the political and economic environment within which it operates, the long term strategic direction, and the ability to assess the impact of decisions taken.

For example, decisions taken during the conceptual design could have a substantial impact on waste handling and final decommissioning costs. The affect can be so great as to outweigh the income and benefit obtained through the operational stage of the nuclear power plant life. Additionally there is an acknowledged expectation that all waste, by-products and structures associated with the nuclear power plant will be actively managed at all times, including decommissioning. Decommissioning may extend over several decades. It is therefore essential to give early consideration and attention to the financial provisions for the costs associated with waste handling and decommissioning and to determine the related strategies to be adopted.

1.2. Objective

The objective of this publication is to promote and communicate the need for a longer-term perspective among senior managers and policy or strategy makers for decisions that have the potential to affect the life cycle management of a nuclear power plant including decommissioning. The following sections provide practical guidance in the subject areas that might have the potential to have such an impact. The publication should be used as an aid to help strategic planning take place in an informed way through the proper consideration of any longer-term decisions to enforce recognition of the point that decommissioning is a part of the whole life cycle of a nuclear power plant.

1.3. Scope and users

The guidance contained in this publication is relevant to all life cycle stages of a nuclear power plant, with particular emphasis on how these decisions have the potential to impact effective decommissioning.

The intended users of this publication are:

– Strategic decision makers within a Utility through all the various life cycle stages
– The senior representatives of the owners of a nuclear power plant.

1.4. Structure

This publication is divided into two basic sections. Section 2 provides guidance on the topics considered generic inputs to plant life cycle management and Section 3 provides guidance on the topics that contribute to effective decommissioning.

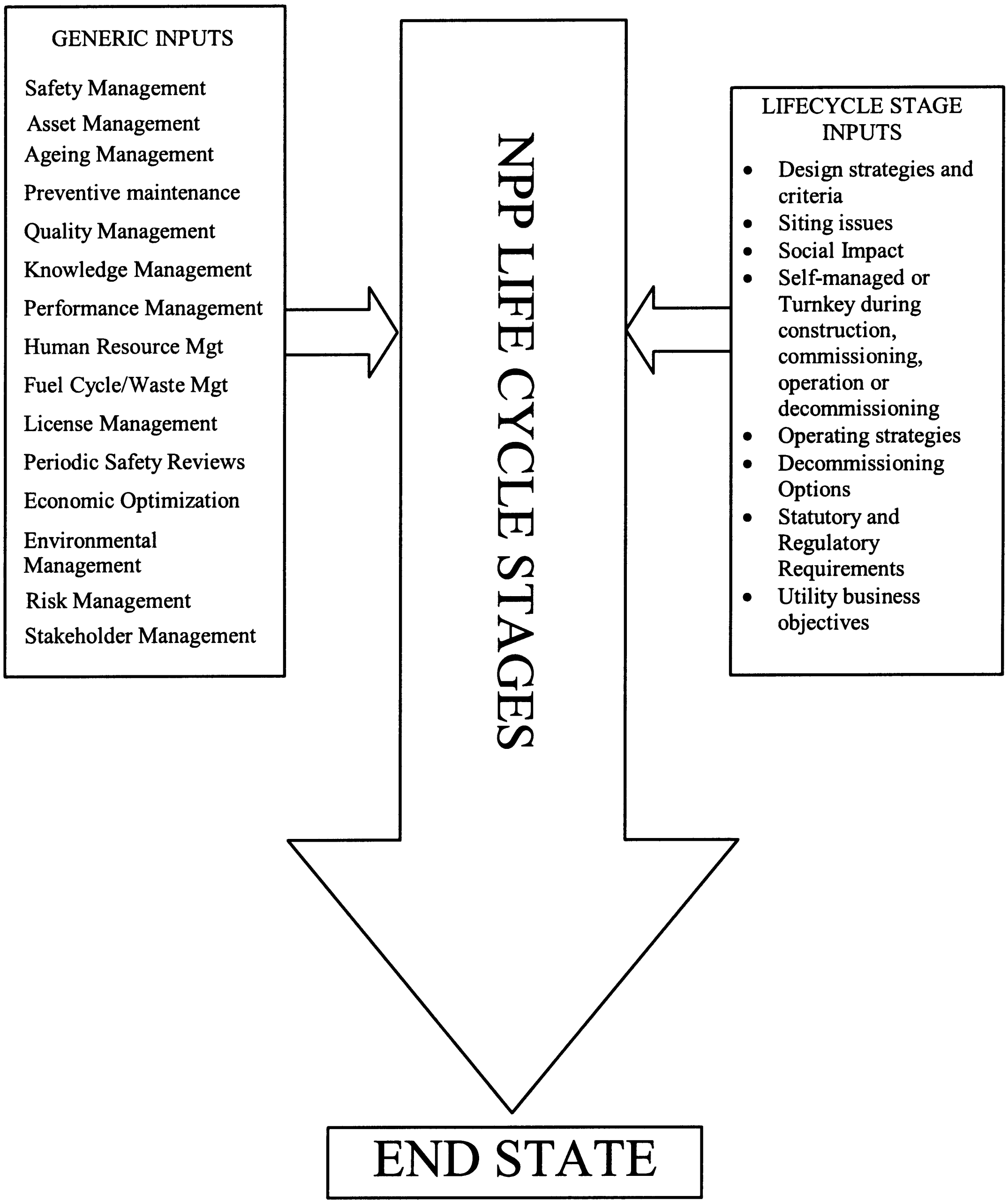

FIG. 1. Inputs to NPP life cycle management.

2. LIFE CYCLE MANAGEMENT

Life cycle management is the integration of safety management, ageing management and business management decisions, together with economic considerations over the life of the nuclear power plant in order to:

- Maintain an acceptable level of performance including safety.
- Optimize the operation, maintenance and service life of structures, systems and components (SSCs).
- Maximize returns on investment over the operational life of the nuclear power plant.
- Take account of national strategies for life cycle funding (including decommissioning), fuel management and waste management.

Figure 1 shows inputs to nuclear power plant life cycle management.

The owners and the public sometimes view a nuclear power plant in the same way as any other industrial asset, but there are three key differences with nuclear power:

- Safety of staff and the public must be of paramount concern in operating a nuclear power plant.
- The amount and longevity of the liability remaining after production of electricity ceases are considerably larger than for most business assets in other industries.
- Ongoing operation may defer the capital expenditure required for decommissioning and waste storage.
- Fund must be collected during operation to meet decommissioning obligations.

The nuclear power plant life cycle should therefore be considered as a single period covering all stages from design through decommissioning (see Fig. 2).

Thus, the period of nuclear power plant life cycle encompasses the early conceptual phase through approval, financing, construction, operation (including periodic safety reviews supporting plant life extensions), shutdown, and decommissioning to the eventual recovery of the site and includes the eventual disposal or re-accountability of responsibility for the fuel and waste. Therefore, in economic terms the full scope of the "life cycle" of a nuclear power plant describes that period when financial charges can be made against the nuclear power plant.

A nuclear power plant is designed and constructed using appropriate codes and standards, high quality materials and procedures, and is thoroughly inspected. The actual plant operational life is defined during the design stage but in many cases is extended during operation when supported by a justification for extended life. This period of operation will determine the amount of total electricity generated by the plant and enable the calculation of the revenue earned.

This revenue-earning period is often the only source for the capital required to cover the costs and the provisions for the whole plant life. In most Member States the nuclear power plant is operated as a business to generate electricity safely in order to secure the revenue to cover the capital costs from design through decommissioning.

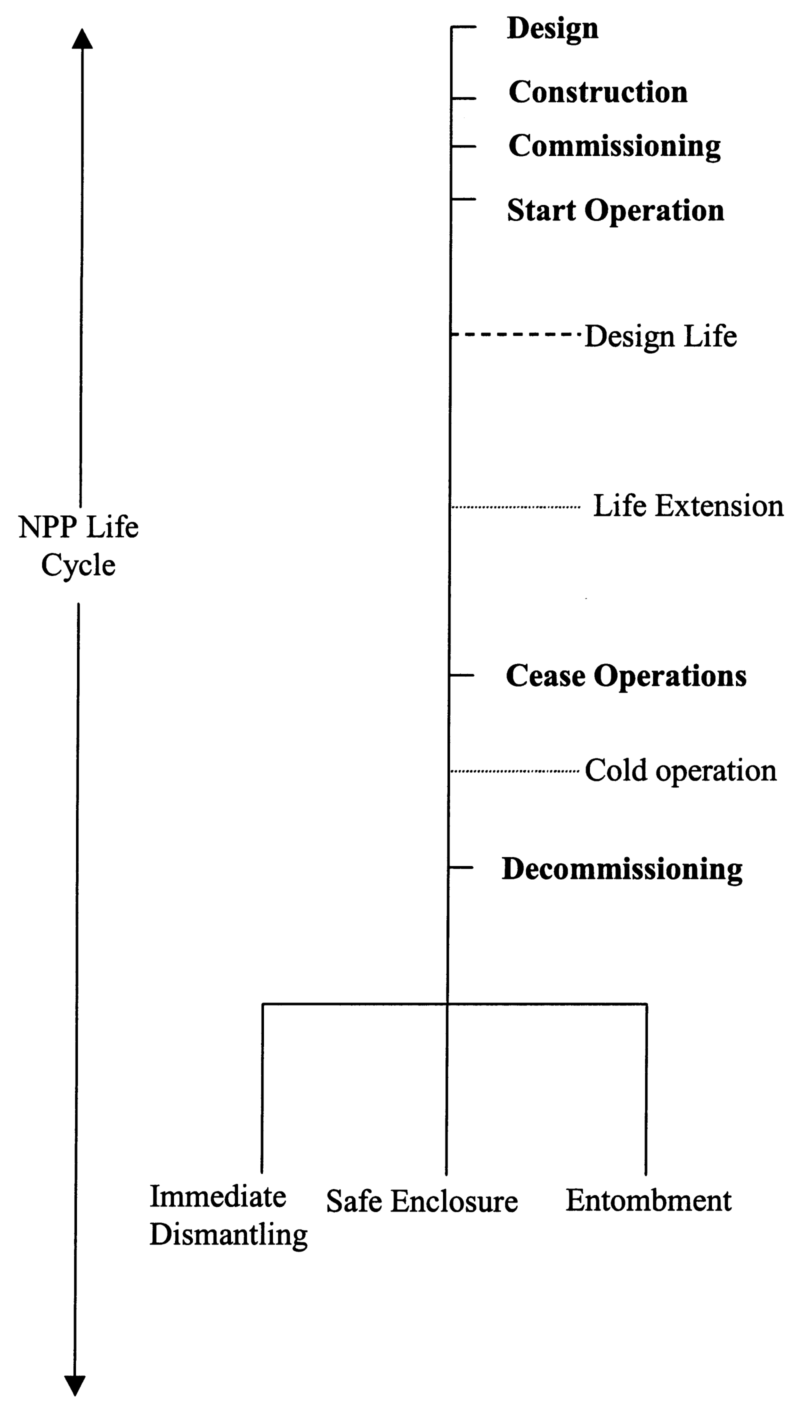

FIG. 2. NPP life cycle.

Electricity markets are experiencing some form of commercialization or competition in virtually all Member States that have operating nuclear power plants. Economic changes, deregulation and restructuring have raised some concerns that nuclear power plants operating under competitive electricity market conditions might fail to honor their duty of funding decommissioning, liability or safety obligations. Life cycle management should enable utilities to be able to demonstrate their commitment to safe operation, their long-term plans and strategies for the plant including the financial provisions being made to cover the cost of safe operation and decommissioning.

Ageing management is a term that describes the combination of:

– Studies of the factors that cause damage to materials and equipment,
– Investigations of ageing and degradation mechanisms,
– The methods and means to reduce the effects of ageing and to maintain equipment operation in a good state of performance and operation.

Safety management is a term that encompasses:

– The achievement of proper operating conditions,
– The prevention of accidents or mitigation of accident consequences, resulting in the protection of workers, the public,
– The establishment and maintenance of an appropriate safety culture.

Recognizing that the nuclear power plant is a business and subsequently directing and managing the business properly is often referred to as "business management". In terms of economics, life cycle management is the methodology (and practice) of optimizing costs to gain maximum profit while preserving competitiveness in the marketplace in the short and long term. Environmental scanning is used in business management to review the business, societal and governmental influences on the organization.

Environmental scanning identifies and examines the effect of external influences to determine their impact on the strategy of achieving the corporate vision and values and may possibly affect the overall nuclear power plant life cycle strategy. For example, the review would examine the following areas for changes that have the potential to affect strategic direction:

– The opinion and expectations of the public.
– The requirements of the safety authorities, for example in challenging technical results, level of safety culture, lifetime of operation.
– The predictions of the electricity market which may result in pressure to lower production costs.
– Any scientific or technical advances and other issues important for the company, which affect the nuclear power plant.
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The integration of activities for ageing management, safety management and business management of a nuclear power plant are an essential element of "life cycle management". Efficient and effective life cycle management that maintains a focus on safety as well as business issues will result in safe and effective operation over the nuclear power plant lifetime.

From a technical point of view, life cycle management is the combination of a number of activities:

– Ensuring the protection of workers, the plant and the environment.
– Minimizing the probability of risks or mitigating against the consequences of some risks.
– Maintaining/enhancing nuclear power plant safety standards.
– Providing operability and durability of the main components and power unit, as a whole.

Information must be captured and recorded progressively through the life cycle to inform and facilitate socio-economic decision making. Analysis of information should ensure that proper attention is given to the factors forming the basis for the decision.

The following topics are important parameters and inputs to enable effective safe life cycle management for the overall life of the nuclear power plant.

2.1. Safety management

Strong economic performance of a nuclear power plant must be driven by excellence in nuclear operation and uncompromising safety. Safety management has two general aims:

– To improve the safety performance of the organization through the planning, control and supervision of safety related activities.

– To foster and support a strong safety culture through the development and reinforcement of good safety attitudes and behaviors.

Safety management is an integral component of the way the whole organization is managed and is described within the quality management system.

The safety performance of an organization should be the subject of periodic assessment through audit and review to provide a measure of the overall effectiveness of the approach to safety management.

Many organizations perform internal assessments and have external assessments by international agencies such as the IAEA performing Operational Safety Review Teams (OSARTs), the World Association of Nuclear Operators (WANO) performing peer reviews, the Institute of Nuclear Power Operations (INPO) performing evaluations, and other assessments performed through the CANDU Owners Group (COG).

The output of all of these assessments should be used by the organization to improve safety performance and to identify corrective actions for longer-term issues having the potential to have a detrimental effect on safety throughout all stages of the plant life cycle.

The objective of safety management within life cycle management is to maintain the safety level of the nuclear power plant higher than the reference level defined in the corresponding safety case.

This general objective of safety management covers two issues:

– The characteristics of the various systems, structures and components (SSCs) related to the safety of a nuclear power plant should not degrade below the values considered in the design, which incorporates provisions for ageing effects.

– The expected and acceptable safety level at the time of design may later come to be regarded as insufficient and its continued acceptability for further operation has to be assessed.

It should be recognized within life cycle management that some SSCs are needed for, or would assist in, maintaining safety during decommissioning. Life cycle management should ensure these SSCs are maintained and remain capable of meeting their design intent until they are no longer required.

It is of paramount importance that any decisions or changes in strategy resulting from safety management consider the implications for all life cycle stages. Safety management decisions and consideration should be adequately recorded to enable any later review during the plant life cycle to understand the basis for any decisions, including the reasoning for the rejection of some options.

2.2. Asset management

Asset management is the business discipline of monitoring and tracking the life cycle of the assets of an organization. The life cycle of an asset begins with its procurement and financing and extends through its maintenance, repair and upgrades, until the asset's eventual disposition. In the case of a nuclear power plant the life cycle of the asset is from design through decommissioning.

An asset is defined as an economic resource, tangible or intangible, which is expected to provide benefits to a business. The primary assets for a nuclear utility are the power plant itself and the staff required to support the plant. It is therefore necessary to ensure that these assets are properly managed, which includes investment to improve them in order to achieve the optimal life of the plant from design through to decommissioning. Asset management is utilized to help organizations optimize their plant and equipment operations to aid in protecting all types of assets to improve availability and productivity and reduce costs at equipment and asset level.

Asset management provides information that empowers management to make both tactical and strategic decisions for the utility. Additionally, asset management helps to lower the costs and increase the safety/productivity of an asset over its life, making for a more efficient and productive organization.

A utility should adopt a clear asset management programme to achieve real and lasting improvements with the objective of longer-term decisions supporting plant life management.

A utility should consider adopting a process, which will locate, identify, count and document the fixed assets and property of the organization. This is achieved through asset inventories, asset tracking solutions, desktop IT asset management and data reconciliation. These activities provide a source of information to aid the improvement of safety, profits, productivity and performance.

Asset management incorporates the following activities:

- Regular physical inspections of SSCs in order to become thoroughly knowledgeable about every aspect of their condition and operation.

- Assessing aspects such as equipment reliability/performance, business processes, data management, organizational structures and training of staff.

- Implementing improvements through a structured and practical approach to change management.

- Improving availability and reduced operating costs through the intelligent application of Reliability Engineering and Integrated Logistic Support techniques.

- Operating and maintaining the plant equipment in order to sustain long term availability and reliability.

- Offsetting plant-ageing impacts.

- Preserving the asset by continuing to operate safely.

- Maintenance optimization through targeting maintenance resources on the real needs of the plant.

- Optimization of logistics and supply chains.

- Staff development to ensure the ‘people’ asset remains effective.

- Alignment with the human resource strategy to ensure there is succession management for key posts.

A structured assessment approach to the analysis of all key aspects of a utilities operation and maintenance functions should aid asset management by identifying opportunities for significant improvement to asset performance (including safety) and profitability. This approach would include:

- Identifying and quantifying problem areas as opportunities.
- Providing a strategy to realize these opportunities.
- Providing an action plan for implementation, detailing time-scales, resources and investment requirements.
- Providing a detailed assessment of benefits and pay-back times-scales.
- Defining qualitative benefits to be gained.
- Setting a base reference point from which future progress can be measured.

Organizations that are good at asset management also ensure that they capture and use organizational learning to aid the structured approach outlined above.

The overall focus and direction of asset management should enable the optimization of plant life management.

2.3. Risk management and decision making

Risk in the nuclear industry is often taken to mean risk to the plant if a certain set of conditions occurs, or the risk to the people due to the same or other circumstances. These “traditional” or often “technical” risks are commonly understood, quantified by methods such as probabilistic safety analysis, behavioral safety studies, and control measures which are put in place to prevent the risks becoming reality, or to mitigate their effect or consequences. The control measures are usually proportionate to the consequences of the event, balanced by the probability of it occurring. This section does not attempt to redefine or elaborate on the many methods for risk assessment and management defined within other IAEA publications.

In the current energy environment there is a need to consider the many dimensions of risk in addition to technical risks. In order to stay competitive in modern energy markets it is necessary to integrate management of technical type risks (production, safety related and environmental impact) with economic risks in an effective way. Deregulation has the tendency to increase the pressure on utilities to cut costs and to be more competitive which has the potential to introduce economic risks to safe operation. These risks have the potential to affect technical type risks if decisions are taken on a purely financial basis only. Risk management should be based on accurate information and not be unduly influenced by uncertainty in the data for example long-term projections of market trends or electricity prices. In this context life cycle management should consider all aspects of risk in order to determine an optimum solution that does not compromise safety and performance. This solution may entail breaking down the overall risk by compartmentalizing it into a number of more manageable risks.

As has been stated the total life cycle of a nuclear power plant may extend up to 100 years when decommissioning is included. This differs from most other businesses, and demands that nuclear power plant management must consider the business environment together with the associated risks and opportunities well into the future.

It is therefore essential that life cycle management properly considers all risks particularly those of safety significance and does not make decisions from a short-term financial perspective.

Safety considerations must be a major input to any determination of business risks in addition to the considerations from a financial perspective. Decision making must consider the impact of any strategic decision on safety, business direction, resources (financial and people) and the long-term vision of success as well as the impact on later stages in the plant life cycle.

The organization should develop an integrated approach to risk management in order to correlate and analyze safety, operational and financial risks in a portfolio context. This approach should ensure that discussions and decisions concentrate on the major issues to determine a proper mix of preventive measures.

The various aspects of running a nuclear utility as a business, such as electricity demand, fuel costs, electricity price, forward planning, etc. are influenced by different but related circumstances. A model for business risk management and opportunity identification can be described in the following steps:

- Define the business area,
- Focus on the desired outcomes in that area which are beneficial to the whole business,
- Identify and prioritize the risks and opportunities (safety and business) by:
  - Assessing the likelihood of the risks and opportunities becoming reality, and quantifying the effects on the business
  - Considering the consequences or benefits against the costs of influencing or mitigating the risks,

- It may be beneficial to consider splitting the management of the risk across the various life cycle stages as the impact and even the risk may differ,

- Establish a response plan to reduce or mitigate the risk or enhance the opportunity with clear responsibilities,

- Implement the plan and review progress and compatibility with organizational objectives and changing business circumstances.

By careful and continuing risk response planning, the nuclear power plant management may be able to influence events in a favorable way. Contingency plans should be utilized to limit any adverse consequences of risks. The effort put into any such contingency planning should be related to the potential consequences if the risk were to materialize.

The integrated approach to managing risks and the output it generates is an input to decision making and the setting of strategic direction for plant life management.

2.4. Stakeholder management

It is important to identify the interested groups or stakeholders who may influence decision making or strategy development, together with their particular interest and information needs. It is vital to communicate with them effectively, at regular intervals, to seek feedback and to be proactive in identifying and quickly resolving any concerns.

It is often beneficial to carry out some stakeholder mapping in order to:

- Identify who all the stakeholders are.
- Identify their position or viewpoint.
- Consider how to best influence the stakeholders.

For example, If a utility is a heat source for the local community there will be pressure to keep the plant operating rather than move into decommissioning; If the internal stakeholder (the staff) view decommissioning as a negative activity there may be a loss of morale, increased sickness levels and in some cases even malicious damage to the plant.

The position or views of all stakeholders should be monitored, as even those presently supportive or neutral to nuclear power may change their attitude or adopt opposing views throughout plant life. It takes less effort to help a stakeholder remain supportive than to win them back.

Early interaction with the public, politicians, pressure groups and the media can help to create a more favorable view of the nuclear power plant and its management as a trustworthy and credible organization that deserves public acceptance.

The formal decision for continued operation of a nuclear power plant is taken in conjunction with a licensing body (usually a governmental body); this decision can be influenced by the demonstration of an effective life cycle management approach within a utility.

Stakeholder management will be enhanced by a clear, continuing commitment to open and honest dialogue with all stakeholders about the performance of the power plant, the long-term strategy and the benefits the plant brings locally, nationally and internationally.

2.5. Ageing management

Ageing management is defined as engineering, operations, and maintenance actions to control within acceptable limits ageing degradation of systems, structures and components (SSCs).

To provide for the timely detection and mitigation of ageing degradation of SSCs important to safety, nuclear power plant owners/operators should have in place a systematic ageing management program, which takes account of regulatory policy and guidance.

Ageing management, as a part of its input to life cycle management, should consider the benefits to the plant of maintaining SSCs in good working order if they would aid decommissioning, rather than taking the short-term view and withholding funding for maintenance during the operational stage. Such SSCs include the fuel route, the active effluent treatment plant and the change room facilities.

The recommendations and actions identified by the ageing management programme provide a major input to nuclear power plant life cycle management. Implementing these recommendations and actions will enable the plant to continue operation or alternatively could indicate when a plant is no longer economically viable to operate.

2.6. Preventive maintenance/predictive maintenance

Maintenance is the administrative and technical activity that keeps structures, systems and components (SSCs) in good operating condition. It includes both preventive maintenance and predictive maintenance as well as corrective, periodic, and planned maintenance.

Preventive maintenance is maintenance performed to detect, preclude or mitigate the degradation of a SSC in order to sustain or extend its useful life by controlling degradation and failures to an acceptable level. Having a well-developed and properly resourced preventative maintenance programme is an essential part of life cycle management, as it will extend the operability of the SSCs.

Predictive maintenance (or condition-based maintenance) is maintenance performed continuously or at intervals governed by observed conditions, which are used to monitor, to diagnose or trend an SSCs condition indicators to identify current and future ability or to identify the nature and schedule of planned maintenance.

In recent years, condition based monitoring and risk based analysis concepts have led to efforts to identify test frequencies and replacement schedules based on analysis of historical performance. Probabilistic risk analysis (PRA) and probabilistic safety analysis (PSA) techniques are providing the foundation for identification of equipment important to safety, which should have attention that is more frequent.

The effectiveness of the maintenance programme can be evaluated using historical data, PRA/PSA and other means to ensure that important equipment is not failing and guidelines, including testing and evaluation procedures and frequencies, can be developed to avoid problems.

It should also be recognized that the maintenance regime and requirements would change as the plant goes through the various life cycle stages. The high risk SSCs within the operational stage may differ from those within the decommissioning stage. In order to ensure that appropriate maintenance and controls are implemented the concept of a graded approach to quality assurance should be used to determine significance, recognizing that the graded approach will itself differ from operations to decommissioning.

Economic pressures have stimulated the nuclear industry to optimize testing schedules to reduce maintenance costs. As a result, efforts are now underway to define objective bases for the frequency of tests performed on the plant equipment. To accomplish this, plant personnel are using equipment performance histories, generic information from databases and the results of ageing programmes.

2.7. Quality management

Management are responsible for developing, implementing and maintaining a quality assurance programme (sometimes referred to as a management system) which defines the way the organization is organized and managed for all the life cycle stages of a nuclear power plant. It provides a systematic tool for accomplishing work with the ultimate goal of doing the job right first time.

Effective life cycle management is aided by ensuring that the management system utilized for the early stages of plant life, adequately address the requirements of subsequent life cycle stages. For example, design should consider factors that aid operation and decommissioning; the operational stage should consider what activities it needs to conduct to aid decommissioning. The management system should also provide adequately recorded data to provide important information in the latter stages of the life cycle.

Recognizing challenges imposed by deregulation, competitiveness, plant ageing, loss of institutional memory, etc., makes it imperative that nuclear power plants pursue continuous improvement in operational safety, reliable and competitive performance, while ensuring adequate control of present day activities. Nuclear power plants are coming under increasing pressure to do more with less.

Management has the unique responsibility to determine how it will achieve the vision/mission of the organization during each stage of plant life. This vision should consider both short and long term improvements in both safety and performance and should be effectively communicated throughout the entire organization and to stakeholders.

It is also important that management provides the vision and inspiration to motivate the organization to higher levels of performance. This leadership is both for present results and also longer-term goals and objectives. For example, decisions and their associated communication must be results oriented and help shape the plant’s future until decommissioning is complete.

The acceptance of external inputs is a basis for growth that is required for continuous improvement. This attitude makes people self-critical which creates an organization that is more open and receptive to the challenges to improve. For any plant, valuable experience can be collected from other plants to focus and anticipate difficulties and to identify potential improvements to the plant's life cycle. Valuable sources also exist within the IAEA (ASSET and OSART missions) and WANO (peer evaluations) that could lead to the identification of long-term improvements that should also be considered as an input to life cycle management

All individuals should be encouraged to contribute to safe and effective plant life management through identifying improvements in the activities associated with safe, cost effective operation, life extension and decommissioning.

During its whole life cycle the plant organization needs to be a learning organization, supported by exchanging information and practices both internally and externally to the organization.

2.8. Knowledge management

The loss of information at any stage of a nuclear power plants life deprives people, at later stages, of knowledge that could be important to safe, economic completion of work or which could aid the analysis of problems and options. It is costly to go through the learning process again, with a risk of potential events or incidents, programme delays, physical injury and increased regulatory surveillance. In some cases, it may be impossible to rebuild information. As a consequence assumptions may have to be made that cannot be easily substantiated.

There is a need to implement a methodology at an early stage in the nuclear power plant life cycle to capture corporate knowledge about decisions, strategies and the reasoning behind these decisions, so that those who were not necessarily part of the decision making process can understand the reasoning. It is important to capture the reasons for not pursuing some options, as this can also be a valuable source of information. Relevant information should be recorded and properly stored to provide objective data for later work. This methodology will ultimately be one of the most important sources of information for life management activities.

An appropriate records system should be established and implemented by the responsible organization as early in the plant life as possible to capture relevant knowledge and information. The records system should ensure that records are specified, prepared, authenticated and maintained, as required by applicable codes, standards and specifications. Examples are: records of siting, design, construction, commissioning, operation and decommissioning. The records should include: the results of inspections, tests, reviews, assessments, monitoring of work performance and material analysis; test materials and specimens; plant operation logs and related data such as training and qualifications and other appropriate data.

Establishing and maintaining an effective records management system is essential to aid decommissioning and to enable the organization to be able to provide the information to demonstrate or support options or strategies chosen, decisions taken and claims made. Identifying and retaining adequate records may lead to cost savings in later stages through not having to repeat work or carry out further studies/justifications.

The need to capture corporate memory is particularly important during the longer stages such as the operational and decommissioning NPP life cycle phases. It is also important to understand the reasoning and issues for major technical activities such as periodic safety reviews or lifetime extension programmes.

Knowledge management should also aim to ensure that dependency on individual memory is reduced, and hence enhance the organization's robustness against changes of personnel as time proceeds. This is particularly relevant as the nuclear power plant approaches the end of operation, as there is a tendency to release large numbers of knowledgeable staff. Knowledge Management should seek to preserve knowledge about plant design, construction, operation and maintenance, so that the knowledge can be transferred to the next generation of plant personnel.

Many of the stages of a nuclear power plant are likely to involve specialist contractors, for example, during design, construction, commissioning and decommissioning. Consequently, corporate knowledge will be mostly found within the contracting organization. This issue should be addressed in the contractual arrangements between the two parties with the nuclear power plant making sure that they retain some expertise to fulfill the role of an informed customer. This situation, if not properly managed almost inevitably leads to a dilution of the knowledge with a consequent risk of omitting information important for the safe and effective completion of work.

2.9. Performance management

Performance management covers many aspects in plant life management. It is important to understand that the better the management team, at an operating nuclear power plant, uses appropriate performance measuring techniques to analyze and manage performance, the better equipped the team will be when providing information to decision makers at a later date about improving or declining trends.

Benchmarking, learning from the practices of best performing companies, trend analysis of plant parameters, monitoring plant performance through system component monitors, corrective action programmes are just some of the methods used to aid performance management. This information must be properly recorded and stored so that it can be retrieved when required to aid plant life management.

2.10. Human resource management

When a nuclear power plant ceases to operate is not simply shut down and left. The nuclear power plant site is still the responsibility of the owner, who must control it, decommission the plant and clear the site to a greater or lesser extent. Each of the transitional periods from operation, to shutdown, to dismantling may occur over a period of many years. At each of the transitional periods, the organization must remain competent to hold the license and own the site.

Strategic decisions about the way the transition will occur will directly influence the human resource strategy, as there will be increased pressure to reduce staff costs and hence numbers. This is particularly relevant as a nuclear power plant approaches the end of the operational or revenue earning period. At this time staff will be uncertain about their future, and may seek to leave because they do not find the new type of work attractive, or they may be looking to secure longer term employment elsewhere. It is often the case that the self-motivated and more valuable staff are the first to leave, as they see no future in the organization.

Because of the pressure to reduce staff numbers, many regulatory bodies are seeking to ensure that utilities properly manage the change and resultant loss of personnel. During each of these transitional periods, the numbers of staff and the types and levels of competence needed to sustain the organization must be maintained. This need should be determined by an objective analysis of the organizations needs. Measures will need to be implemented to ensure that enough competent staff is retained. It should be recognized that the mix of expertise would change during the transitional periods as well as the life cycle stages.

It is therefore essential that the strategies for plant life management are developed with sufficient clarity to enable the associated human resource strategy or long term Human Resources plan to be developed. This strategy/plan should be reviewed and updated periodically to verify that it is consistent with and supports the nuclear power plant life cycle needs.

The human resource strategy/plan should include, for example:

- How to anticipate and address changes in staffing levels,
- The forecast personnel needs,
- Consideration of the introduction of inducements to retain key staff,
- Developing inducements to encourage staff to leave voluntarily,
- Ensuring the age profile of staff does not leave the nuclear power plant with a competence shortfall,
- Developing and implementing effective succession planning for key positions,
- Enabling the organization to obtain and retain the skilled, committed and well-motivated workforce it needs,
- Ensuring that sufficient numbers and appropriate composition of qualified personnel are maintained,
- Allowing sufficient time for individuals to turn over job responsibilities and allow for continuity in the conduct of duties in advance of planned changes,
- Addressing losses due to retirement and attrition.

2.11. Fuel cycle/waste management

Fuel cycle management should address energy effectiveness, with the objective of generating the maximum electricity from the fuel, balancing the build up of radioactive waste and liabilities, long term political aspects of fuel reprocessing, and eventual disposal.

Public concern and large costs make waste management a strategic topic for plant life management. Although radioactive waste is the main concern, chemical, lubricants and toxic material must also be controlled and reduced. This implies that waste management must be planned and considered during operation to limit accumulation.

The operator must be highly responsible in meeting the highest standards to ensure the best possible long-term performance of processed waste. This obliges the operator not only to reduce the volume of waste as much as reasonably practicable, but also to plan for the best way to store waste in the long term and eventually dispose of it.

It is imperative that strategic decisions regarding fuel and waste management are properly considered in the context of the life cycle management of the nuclear power plant. It is often the case that strategic decisions taken during operations do not consider the implications on the longer-term decommissioning activities. It is important to ensure that such decisions are informed decisions. As an example longer-term decisions affecting waste storage taken to address safety requirements and limit costs at the end of electricity generation, should not be taken if information is not available regarding the disposal facility.

There is often pressure on the decisions taken during operations to focus on maximizing output rather than optimizing output considering fuel, waste and decommissioning needs. Strategic fuel and waste management decisions should consider the benefit and address the impact to the overall nuclear power plant life cycle strategy.

2.12. License management

Operating (or decommissioning) licenses for nuclear power plants are usually granted for a fixed term in most Member States. It is important for the organization to ensure that it meets licensing requirements through all the various life cycle stages, and that it can adequately demonstrate compliance to the regulator or other interested groups. A utility will normally establish a group whose primary role is to interact with the regulator to understand regulator expectations and to ensure that the plant understands and implements any legal or regulatory requirements. The license management programme should be in place from the outset of a proposal to locate a nuclear power plant through all subsequent periods of the nuclear power plant life cycle, including de-licensing. The status of commitments made on behalf of the nuclear power plant should be tracked through to completion.

In many Member States, the performance of the nuclear power plant against the license is reviewed periodically, to ensure that it is adequate and to detect adverse performance trends. Many Member States have no absolute limit on the life of a nuclear power plant, and as long as the nuclear power plant can demonstrate that it is safe to operate, they can continue operating beyond the original design life.

Proactively managing licensing activities should result in periodic reviews being part of ongoing activities rather than a large single project. This continuous approach is more cost effective when implemented as an element of plant life cycle management.

The implications of failing to meet license requirements are costly, and remedial actions consume time and energy of staff, which could be deployed on work more beneficial to the organization's goals and objectives.

Member States evaluating the possibility of extending licensing periods or in renewing license applications should ensure that the nuclear power plant has effectively monitored regulatory changes and emergent strategies during the life cycle of the nuclear power plant.

During any decision making process, the results of an effective license maintenance programme can provide informed advice to executive management about the cost benefits and cost detriments to proceeding with important decisions concerning license issues.

License commitments, having been recognized and identified, should be integrated with supporting objective information and known status into any cost/benefit analysis for future decisions. The output from this activity is naturally an input to strategy and life cycle management and will form the basis for many lifetime extension decisions.

2.13. Periodic safety reviews

Periodic safety reviews should be carried out at regular intervals during the operational stage in order to substantiate safe and reliable plant operation.

The review process should:

- Confirm that the nuclear power plant and SSCs are safe for a defined period of future operation,

- Assess the effects of ageing in order to conservatively estimate the ability of SSCs to perform safely during the defined period,

- Consider the impact of modifications, operating experience and technical developments,

- Identify and evaluate factors that could limit safe operation during the defined period,

- Compare the original design safety case against current safety standards and requirements,

- Identify achievable improvements.

The periodic safety review should look forward over a sufficiently long period of potential future operation of the nuclear power plant (for example 10 years). The review would provide confidence that it is technically feasible to operate the plant consistent with the applicable safety standards.

The results of periodic safety reviews are effectively an input to plant life management

As they aid plant life extension studies and the decision making regarding the investments required to secure an extended operating life.

The decision to proceed with any plant life extension must be based on:

- A good safety performance record,
- The capability to operate the plant safely during the proposed extension,
- Sound economic assessment showing benefits from the investment,
- Public confidence.

Periodic safety reviews should utilize traditional project management techniques as the work is non repetitive, has specific deadlines, probably exceeds the normal capability of the organization, and will require many complimentary skills and objectives. It also needs to analyze all the potential options in order to make appropriate informed choices.

Periodic safety reviews are also utilized during the decommissioning stage. In such cases, they are used as a justification to support the decommissioning strategy that take into account the changes in plant configuration and continued availability of SSCs to ensure decommissioning is carried out safely.

As the nuclear power plant operational stage proceeds, the decision to consider a plant life extension and its financing beyond determined life includes evaluating the benefits and costs considering the return on investment from any capital invested as well as safety factors. Ultimately, a position could be reached where it would be uneconomic to modify the plant or operating procedures, which determines the potential end of the operating lifetime of the nuclear power plant. This activity would include estimating the current net present value of the nuclear power plant and the net present value at some future date.

From this “business” starting point a number of factors, which have an impact on cost, have to be considered, such as establishing need, development of the new safety report, estimated cost, infrastructure organizational requirements, (which includes procurement strategy, component supply, training, new regulatory requirements for an older operating unit, financing, financial arrangements and guarantees). Permission to proceed has to be sought to upgrade the plant and plant systems. This could require the generation of a large amount of information on the need for the plant as a major investment and the plant's potential for generating a profit for the Company and its Shareholders. The costs of all these activities have a direct bearing on the costs to be recovered during the extended operational stage.

For a plant seeking life extension, the assessment has to be started in advance of the end of the design life. This is necessary so that the main issues for life extension can be identified early enough to enable an engineering programme to be deployed so that any necessary modifications are completed before life extension begins. It is necessary to identify significant issues that have to be identified and resolved in sequence as they may affect the feasibility or case for pursuing other modifications. For example, there is no point in refurbishing the instrument and control systems of a plant if it is later found that embrittlement of the reactor pressure vessel would have mandated early closure.

Another factor that needs to be considered in any decision to extend the operating life of a nuclear power plant is the current environment and attitude to nuclear power. Many factors such as national policy, legislative hurdles, public opinion and energy needs should be evaluated to ensure success for the project.

Plant life extension should also consider the question of spare parts: do they have to be designed and built according to current rules when they have to fit in a mature plant? As we are dealing with single components, the applicable rules are generally not the general safety requirements given by regulatory texts, but the codes and standards established by industry.

In addition, nuclear power plants were designed and built at different times using contemporary or other national Codes and Standards. Codes and Standards naturally evolve over time. Some countries as part of their own industrial development are also, in turn, developing their own Codes and Standards. The original suppliers can no longer provide major components for many older plants because some manufacturers are no longer in that business, the manufacturing methods have been substantially changed, the current material choice, and specifications are significantly different to those in older components.

The full evaluation of components for operational lifetime assessment is a large task requiring the application of a large resource of manpower and data, and is normally part of the continuous equipment qualification programme within the overall maintenance programme. However, the potential benefits in terms of plant life assurance and extending the operational life of nuclear power plant are great.

2.14. Economic optimization

Preserving the existing electricity generation capability is an attractive proposition in many Member States, given national energy strategy issues, growing demand, the limits of energy conservation and opposition to new nuclear power plants. Additionally, life renewal for a nuclear power plant is attractive, as it only involves marginal costs, as capital cost is likely to have been recovered during the planned generating period.

Among the objectives of economic optimization over the life cycle of an nuclear power plant are:

- Maximizing income and/or profit,
- Controlling or reducing the cost of operation, maintenance and waste management,
- Increased load factor,
- Funding, payment and financial planning for decommissioning,
- Securing disposal routes for all types of waste,
- Clarity about ownership liabilities (e.g. reprocessing by-products held by a third party).

This optimization must take place in the full knowledge of potential effects on many other factors, such as safety, plant degradation, accumulation of wastes and liabilities.

The criteria governing economic optimization should be:

- Safe and economic plant operation to the original design period and beyond if necessary,
- Safe and economic decommissioning to an acceptable condition,
- Enhancements to plant safety to enable long-term sustainability and performance.

Economic optimization should take place from a basis of informed knowledge of the risk environment affecting the nuclear power plant both currently and in future life cycle stages.

It is possible that some refurbishment projects that could aid decommissioning are developed and funded during the operational phase, for example, the refurbishment of Active Effluent Treatment plants. The cost/benefit analysis of such a refurbishment project should take into account the benefits to be obtained during decommissioning.

Early consideration of decommissioning strategies and scenarios can and should aid decision making during the operating stage (and possibly earlier during design and construction), in order to ensure that there is overall nuclear power plant life cycle cost optimization, and to ensure that cost optimization is not focused on the needs of one of the life cycle stages. For example, the operational stage may defer a decision to remove redundant and sometimes hazardous plant and equipment because of the cost implications to the operating organization. They choose to defer the responsibility and cost to the decommissioning organization, introducing risk from potential hazards and resulting in an increase in overall costs.

2.15. Environmental management

It is generally recognized that nuclear power plants have a positive influence on the environment by reducing pollutants in the air. A pro-active, pre-planned environmental management strategy seeking to minimize the impact on the environment should be established during the design stage, and actively implemented through the entire life cycle of a nuclear power plant.

Safe and effective nuclear power plant life cycle management should consider the overall environmental impact of the nuclear power plant and seek to minimize the impact to acceptable levels. The information gathered in monitoring the impact on the environment should also be beneficial when considering plans to build a new nuclear power plant.

Environmental considerations will greatly affect any decisions to build future nuclear power plants. A nuclear power plant designed to help address and meet environmental concerns in the future, as well as the present, would support the competitive utilization of new nuclear generation capabilities.

3. DECOMMISSIONING PLANNING

Planning for decommissioning is part of the life cycle management programme for a nuclear power plant. Decommissioning is a unique part of the life cycle and requires a different set of activities to be managed, in order to produce positive results for all stakeholders.

Decommissioning planning is aligned with any national strategies for spent fuel disposal and waste disposal. In the early stages of the nuclear power plant life cycle, the funding strategy for decommissioning is clearly defined, so that funding can be planned and provided for:

- Fuel,
- Waste disposal,
- Site cleanup or re-use.

3.1. Specific end of life cycle considerations

Planning during the operation stage for the shutdown and decommissioning of a nuclear power plant allows time to properly consider issues related to:

- The actual decommissioning process, and,
- The site personnel affected by the cessation of operations, and decommissioning of the facility.

Recent history has been dominated by decommissioning experience resulting from pre-mature unplanned shutdowns. This has resulted in a slow start for the decommissioning process, with significant costs being incurred because of inefficient use of the operating staff, before, and immediately after shutdown. Future strategies should learn from this experience and take advantage of the operating period by being proactive in planning, and implementing many of the critical transition and decommissioning activities.

In the context of life cycle management, detailed decommissioning planning should begin 5 years before the planned transition into implementing the decommissioning option. Decommissioning planning should be considered as a part of design and construction activities. The course of action available to the plant owner is closely coupled to the length of the planning window. The risk of a shorter planning window is that many more tasks must proceed in parallel. The consequence may be reduced project integration, increased project risk, and increased project cost.

Experience over the last forty years has shown that effective planning and early decision making, in relation to the design and operation of a nuclear power plant, is paramount to support optimization of cost and competitiveness. Pre-planning as early as the early design stage for issues concerning the end state of the nuclear power plant, and the associated site, may result in a better economic optimization of the nuclear power plant life cycle.

3.2. End state

The choice of a decommissioning strategy will depend on the following considerations regarding the future end-state of the nuclear power plant:

– Safety considerations.

– If the owner has a shortage of sites for new plant construction requiring re-use of a site for a new plant. In this case, immediate dismantling may be chosen.

– If the plant to be decommissioned is located on the same site as other operating facilities that will continue to be in service, safe enclosure may be the preferred choice. The necessary security, surveillance and maintenance for the shutdown facility could be provided by the remaining operating facilities.

– If in the decision to implement the safe enclosure option, the owner wishes to consider the re-use of some of the plant facilities, for example the cooling water equipment, and some of the plant process systems, for purposes other than those for which they were originally intended or as part of a new or modified plant.
– If the decision is for entombment, appropriate methods and processes are identified.

– Governmental or Regulatory pressures to shut down operating plants and decommission within specific timescales.

– Public input may be needed to determine choice.

– The availability of repositories for intermediate and high level waste storage.

3.3. Choice of decommissioning option

Single unit plants with access to low level waste disposal options will generally choose the immediate dismantlement option. This option results in the most rapid return of the site to original condition. Cost studies have shown this option to be cost competitive with the other options.

Multiple unit sites with one or more reactors still in operation have generally elected a deferred dismantlement option. The close proximity of the other units is not the only issue of concern; many multiple unit sites have shared systems between the units. Decommissioning one of a number of these units may present unacceptable risks. In such instances, most of the systems in the shutdown and defuelled unit, i.e., those not shared with the sister unit or required for long term fuel storage, are placed in lay up to await the joint decommissioning of the units upon the permanent shutdown and defuelling of the last unit on site.

When a plant is eventually shut down and defuelled, pre-planned decommissioning funding must be made available, as no income from energy sales is possible after operation. Availability of funding and the optimization of pre-planned expenditure for this period of plant life management are integral to competitive electricity production. The planning of funding and accumulating the required funds for decommissioning should have been established during the operational stage and kept in a separate budget or account that is not used to fund operational activities.

3.4. Self-managed or turnkey decommissioning project

Plant closures present a number of human resource challenges to management. One of the largest variable costs, post shutdown, will be staffing. Sequencing of the decommissioning project will be affected by many of the socio economic issues relevant at the time. This could result in decommissioning being a self-managed project or a turnkey operation managed by contractors.

At the same time, pre-planning for the shutdown also permits the licensee to determine, well in advance of necessity, the complement of talent required to execute the decommissioning strategy. As a result, many licensees have been creative in developing retention/severance/ early retirement packages to shape the evolution of the plant staffing to meet their projected requirements. This can prove to be cost effective for the company while also easing the transitional burdens for employees.

One of the key factors in development of such human resource management programmes is the predetermination of the role to be played by the existing plant staff in the decommissioning process.

Experience has shown that a separate management team with responsibility for the decommissioning unit can be an effective strategy. Decommissioning is then clearly seen as differing from operation in terms of the mission, goals and objectives of the organization and the skills and attitudes needed in the staff. By providing a separate management team, the managers have clear "ownership" of the decommissioning mission and can focus on the decommissioning activities. The team should have direct access to top plant management.

In many cases, there is a need for an increased reliance on contractors during decommissioning. This has created the potential for problems associated with the oversight of the decommissioning activities by the licensee, the retention and learning from those carrying out the decommissioning activities, communication amongst the regulator, the licensee, and the contractor and any subcontractors.

It is important that the licensee have complete knowledge and control over the work being performed. A number of examples exist where extensive use of contractors has been successfully managed. The keys to success have been identified as the provision of adequate measures to retain competence within the licensee organization such that the licensee could provide effective oversight of the contractors.

3.5. Social impacts

The process of deciding between the different decommissioning strategies may take into consideration the possible effects on factors such as:

- Environmental factors (e.g. the value of the neighboring land),
- Employment problems,
- The public's perception of the hazards, whether the installation is maintained in a safe shutdown condition or is dismantled.

Public opinion about the proposed choice should be considered in the final strategy to be adopted. This may include obtaining approval of the strategy by relevant authorities or regulatory bodies. The requirements for approval, notification and concurrence of these bodies vary from Member State to Member State.

Decommissioning activities are almost certain to draw attention from a number of stakeholders. This would include community members, the media, activists, political and business leaders, and the employees themselves. This attention will not always be positive. The nuclear power plant communication programmes must be tailored to meet the needs of all stakeholders.

In designing a programme to communicate decommissioning with either employees or the public, it is essential to build on the communication programme deployed during the operational stage. The use of this programme by the decommissioning organization should ensure that they communicate consistent, timely, and accurate messages to respective stakeholders.

It is generally accepted that “people issues” present the single largest challenge to management in the decommissioning process. Two challenges are to be confronted. Firstly, employees are well aware that plant staffing will be dramatically reduced shortly after or within months of shutdown. Secondly, that the decommissioning process involves "working oneself out of a job." Preplanning can blunt the negative impact of both. This should be factored into the nuclear power plant life cycle human resources strategy discussed earlier.

3.6. Waste disposal

Over the long term, low, intermediate and high level waste repositories must be available for any dismantlement activities to proceed during decommissioning. These repositories may at the outset be of an interim nature if there is no national policy. If there is no national policy concerning repositories for intermediate and high level waste, then the safe enclosure option may be preferential to dismantlement.

Plants that delay dismantlement may not have to deal with the current uncertainty regarding waste storage and disposal that adds complexity to the conditions under which dismantling of the site is carried out. This may be considered as simply passing the issue to future generations to resolve.

3.7. Decommissioning culture

As a plant prepares for decommissioning, an important consideration is how the plant closing will affect the plant culture. Decommissioning is often regarded as a less important activity as it does not generate value in the same way as generating electricity. It is therefore essential to interest and motivate high quality staff associated with decommissioning. The utility should communicate positive messages to ensure that staff considers decommissioning, not as the end of something but as the condition for an ongoing nuclear industry.

To be successful, the majority of the workforce culture must change from a “generation mentality”, associated with the safe and reliable operation of a nuclear plant, to that of a "decommissioning mentality" focused on safe decommissioning. If this cultural shift does not occur, the decommissioning will be impacted with higher costs and scheduling delays.

This issue is particularly important if the utility performs its own decommissioning activities with the plant personnel providing the engineering, planning, and labor resource. Alternatively, if a large infusion of contractor personnel occurs, the cultural transformation may be easier since contract personnel will not possess the generation mentality.

3.8. Decommissioning knowledge

Currently there is commercial experience associated with the implications of extended periods between permanent shutdown and dismantling of commercial NPPs. Commercial nuclear-powered generation of electricity itself is less than 50 years old.

Experience from dismantling as a part of decommissioning nuclear power plants will lead to continued development and improvement of the competence required for dismantlement. A large number of nuclear power plants are being decommissioned now and some of these are being immediately dismantled. Plants that delay dismantling should benefit from the experience gained by plants that have already been dismantled. The competence of workers carrying out dismantlement will improve as they have experience with more plants.

3.9. Technology application

There will be significant technological advances in the methods available for dismantlement. Current experience with decommissioning has demonstrated that new methods are developed as more plants undergo the process of decommissioning. Significant technological breakthroughs can be expected especially when considering the long periods planned for decommissioning. Whilst new advances can be anticipated, a degree of care should be taken before introducing novel techniques or methods to aid decommissioning. It may be more prudent to evolve current approaches rather than introduce radical change.

Decommissioning is being carried out safely with current technology. New technology may make decommissioning, safer, quicker and cheaper.

DEFINITIONS

Ageing degradation: ageing effects that could impair the ability of an SSC to function within acceptance criteria.

- *Examples:* reduction in diameter from wear of a rotating shaft, loss in material strength from fatigue or thermal ageing, swell of potting compounds, and loss of dielectric strength or cracking of insulation.

Ageing management: engineering, operations, and maintenance actions to control within acceptable limits ageing degradation of SSCs.

- *Examples* of engineering actions: design, qualification, and failure analysis.
- *Examples* of operations actions: surveillance, carrying out operational procedures within specified limits, and performing environmental measurements.

Life cycle management: integration of ageing management and economic planning to: (1) optimize the operation, maintenance, and service life of SSCs; (2) maintain an acceptable level of performance and safety; and (3) maximize return on investment over the service life of the plant.

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